US009396226B2

(12) **United States Patent**
McKenney

(10) **Patent No.: US 9,396,226 B2**
(45) **Date of Patent: *Jul. 19, 2016**

(54) **HIGHLY SCALABLE TREE-BASED TRYLOCK**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 258 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **13/924,667**

(22) Filed: **Jun. 24, 2013**

(65) **Prior Publication Data**

US 2014/0379676 A1 Dec. 25, 2014

(51) **Int. Cl.**
G06F 17/30 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 17/30359*** (2013.01)

(58) **Field of Classification Search**
CPC G06F 17/3008; G06F 9/526; G06F 17/30359
USPC 707/704
See application file for complete search history.

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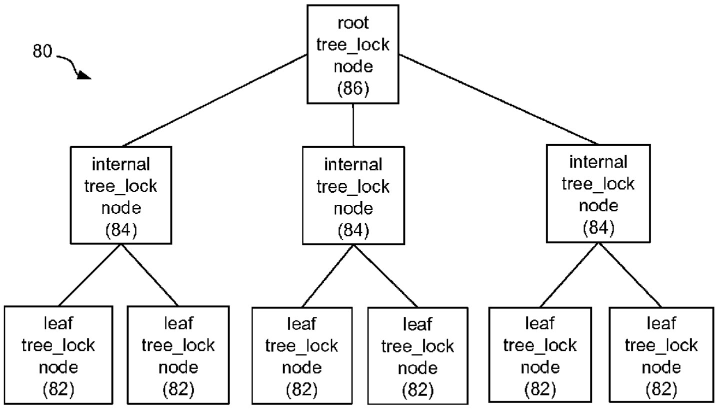
(57) **ABSTRACT**

A tree-based trylock technique for reducing contention on a root trylock includes attempting to acquire a trylock at each node of a tree-based hierarchical node structure while following a traversal path that begins at a leaf node, passes through one or more of internal nodes, and ends at a root node having the root trylock. The trylock acquisition operation succeeds if each trylock on the traversal path is acquired, and fails if any trylock on the traversal path cannot be acquired. A trylock housekeeping operation releases all non-root trylocks visited by the trylock acquisition operation, such that if the trylock acquisition operation succeeds, only the root trylock will be remain acquired at the end of the operation, and if the trylock acquisition operation fails, none of the trylocks will be remain acquired at the end of the operation.

13 Claims, 11 Drawing Sheets



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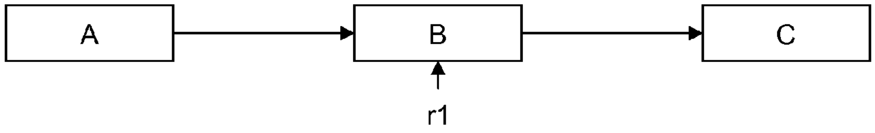
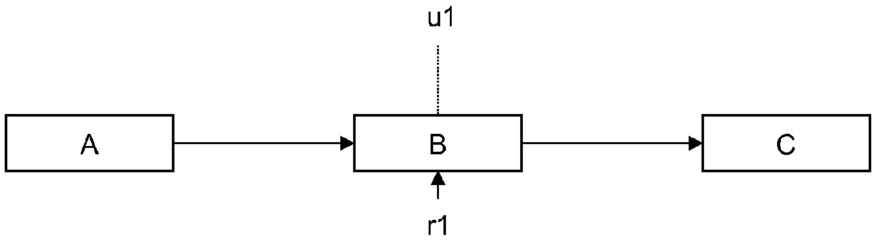


FIG. 1A (PRIOR ART)



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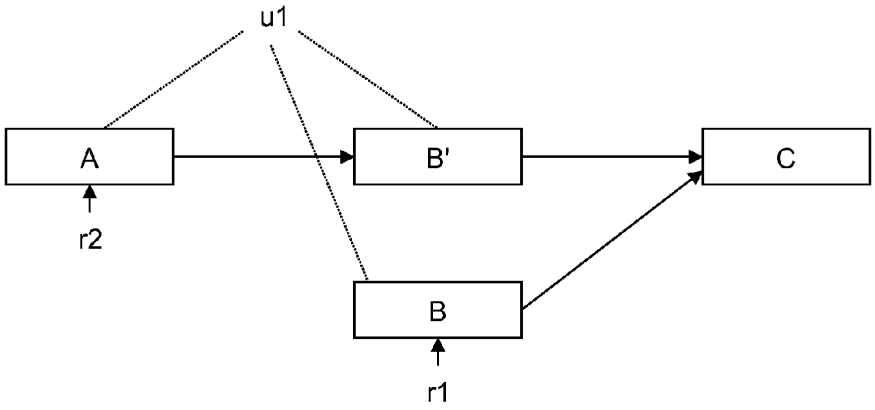

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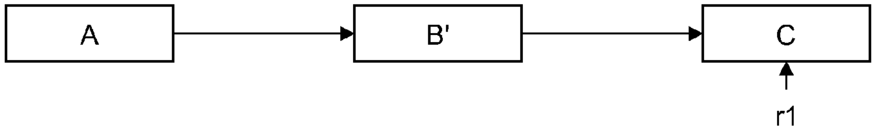

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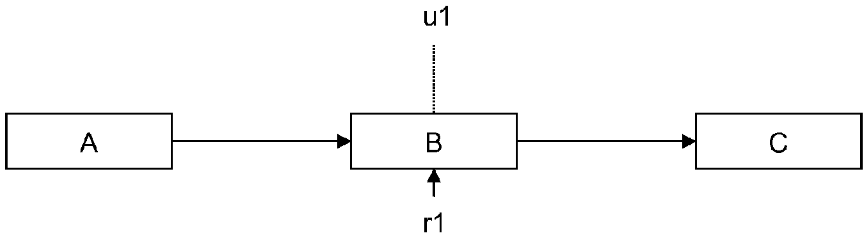
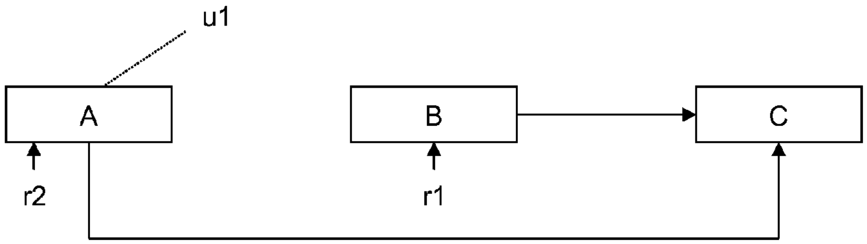


FIG. 2A (PRIOR ART)



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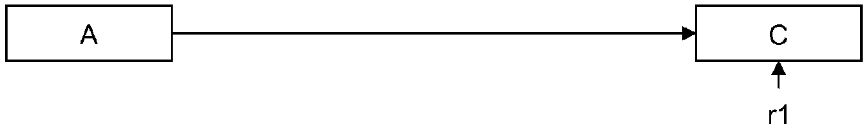

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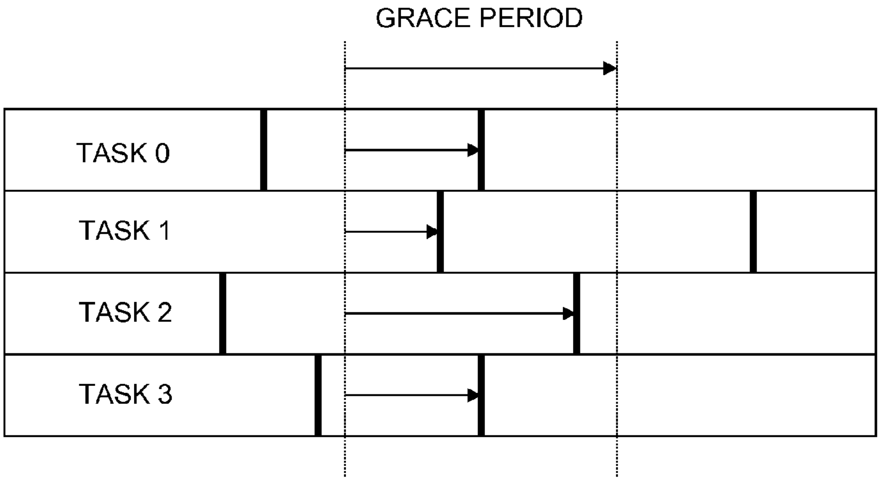

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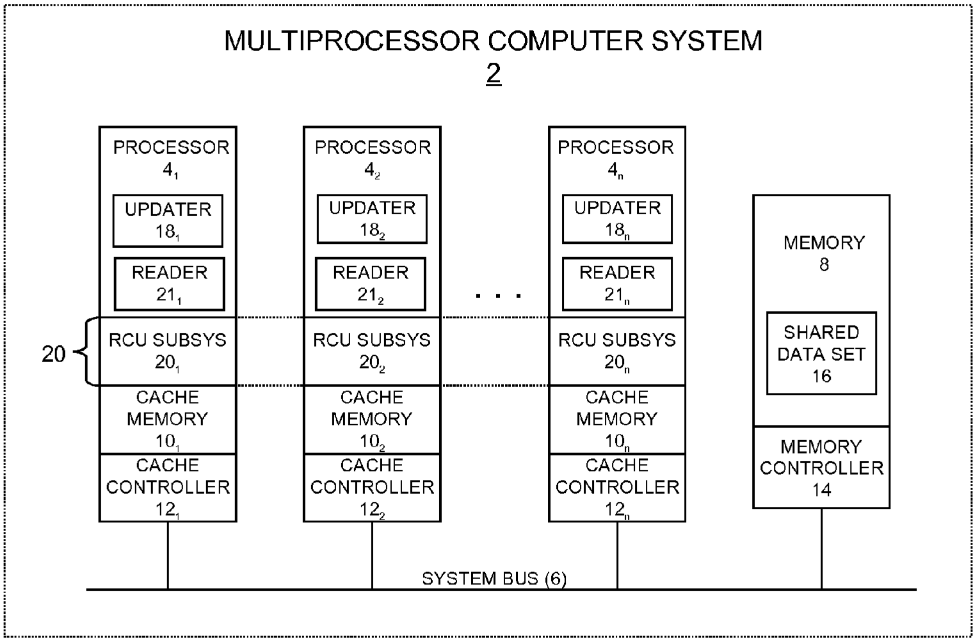

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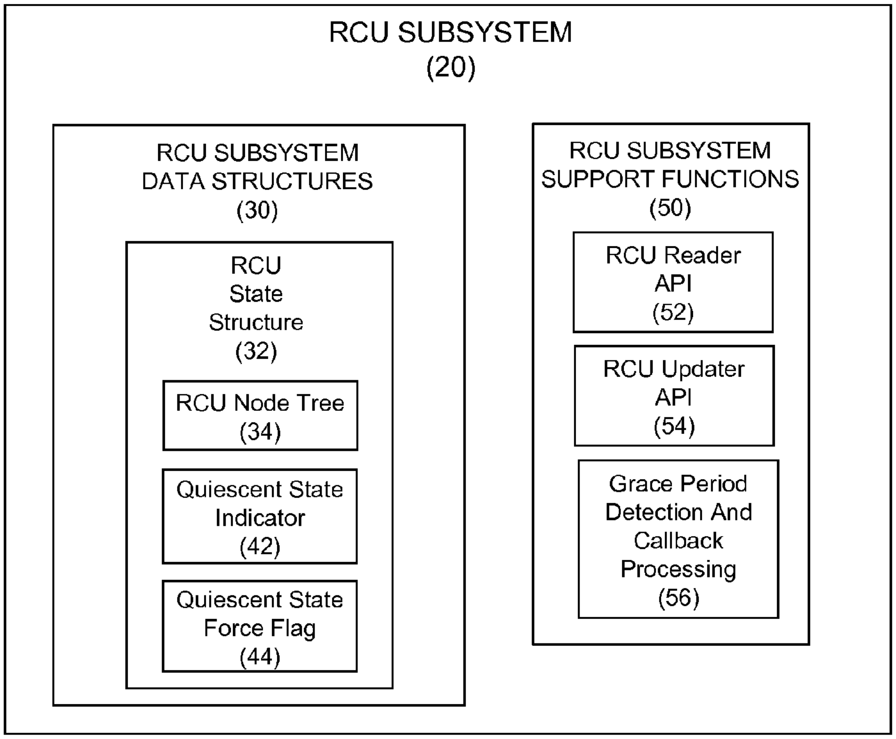
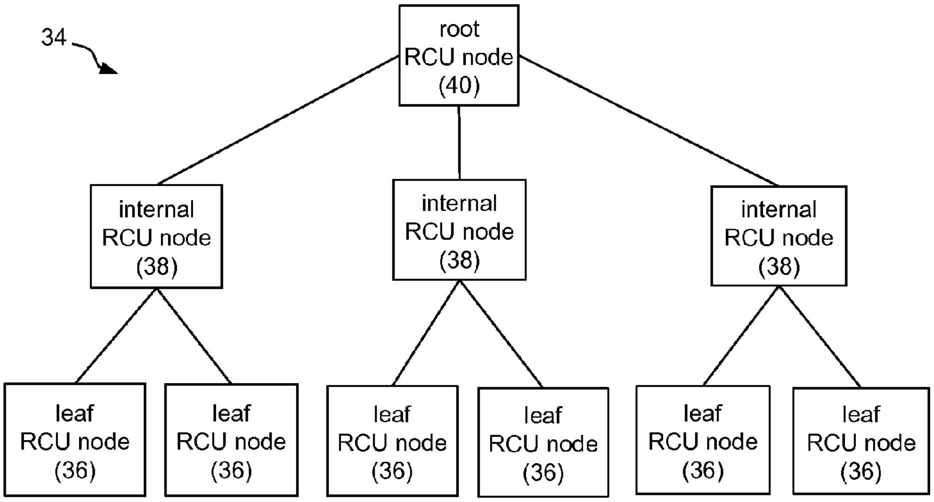

RCU SUBSYSTEM
(20)
RCU SUBSYSTEM
DATA STRUCTURES
(30)
RCU
State
Structure
(32)
RCU Node Tree
(34)
Quiescent State
Indicator
(42)
Quiescent State
Force Flag
(44)
RCU SUBSYSTEM
SUPPORT FUNCTIONS
(50)
RCU Reader
API
(52)
RCU Updater
API
(54)
Grace Period
Detection And
Callback
Processing
(56)

FIG. 5


34
root
RCU node
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internal
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FIG. 6

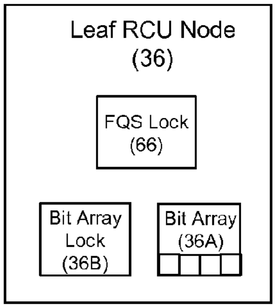
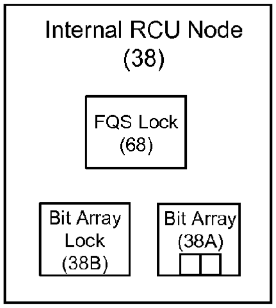


FIG. 7



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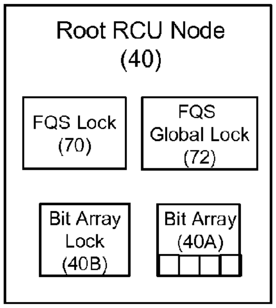

FIG. 9

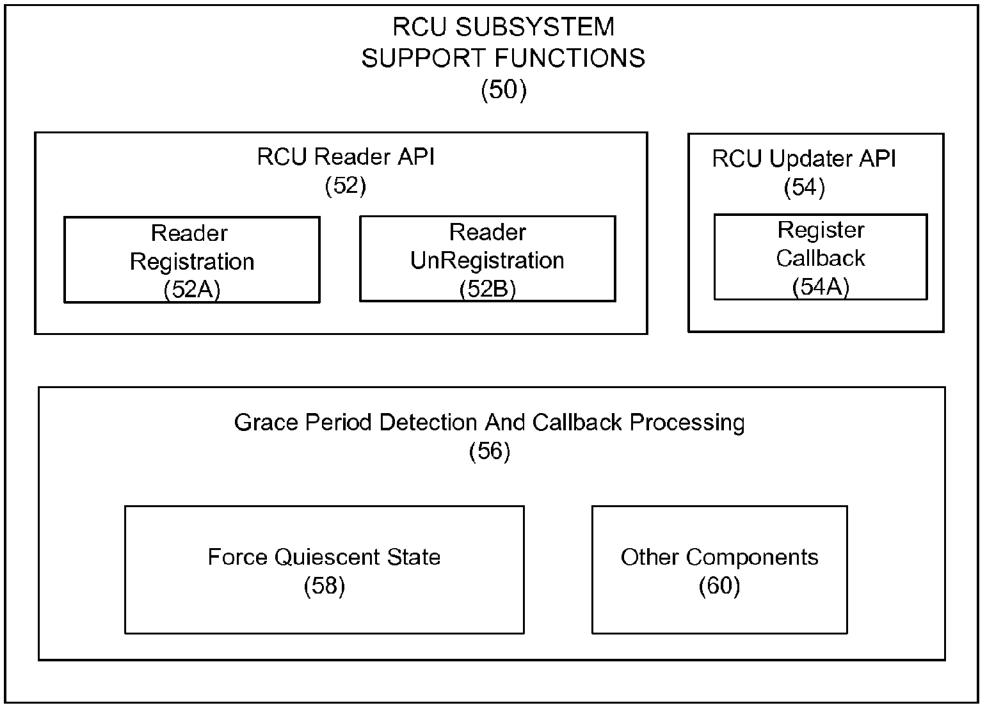

FIG. 10

```
static void force_quiescent_state(struct rcu_state *rsp)
{
  unsigned long flags;
  bool ret;
  struct rcu_node *rnp;
  struct rcu_node *rnp_old = NULL;

  local_irq_save(flags);
  rnp = __this_cpu_ptr(rsp->rda)->mynode;
  for (; rnp != NULL; rnp = rnp->parent) {
    ret = (ACCESS_ONCE(rsp->gp_flags) & RCU_GP_FLAG_FQS) ||
          !raw_spin_trylock(&rnp->fqslock);
    if (rnp_old != NULL)
      raw_spin_unlock(&rnp_old->fqslock);
    if (ret) {
      rsp->n_force_qs_lh++;
      local_irq_restore(flags);
      return;
    }
    rnp_old = rnp;
  }
  raw_spin_lock(&rnp_old->lock);
  raw_spin_unlock(&rnp_old->fqslock);
  if (ACCESS_ONCE(rsp->gp_flags) & RCU_GP_FLAG_FQS) {
    rsp->n_force_qs_lh++;
    raw_spin_unlock_irqrestore(&rnp_old->lock, flags);
    return;
  }
  rsp->gp_flags |= RCU_GP_FLAG_FQS;
  raw_spin_unlock_irqrestore(&rnp_old->lock, flags);
  wake_up(&rsp->gp_wq);
 }
```

FIG. 11

```
struct tree_lock {
spinlock_t try_lock;
struct tree_lock *parent;
struct tree_lock *root;
int failcount;
};

int tree_try_lock(struct tree_lock *leafp,
                 bool (*check)(void *arg), void *arg)
{
  bool ret;
  struct tree_lock *tlp;
  struct tree_lock *tlp_old = NULL;

  for (tlp = leafp; tlp != NULL; tlp = tlp->parent) {
    ret = check(arg) || !spin_trylock(&tlp->try_lock);
    if (tlp_old != NULL)
      spin_unlock(&tlp_old->try_lock);
    if (ret) {
      tlp->failcount++;
      return 0;
    }
    tlp_old = tlp;
  }
  return 1;
}

void tree_unlock(struct tree_lock *leafp)
{
  struct tree_lock *tlp = leafp->root;

  spin_unlock(&tlp->try_lock);
}
```

FIG. 12

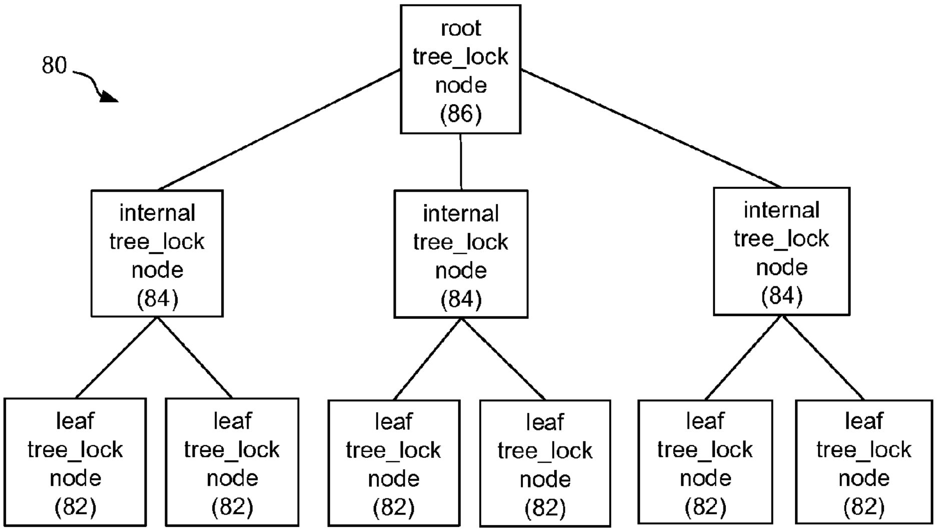

FIG. 13

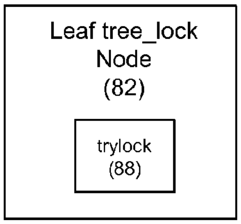

FIG. 14

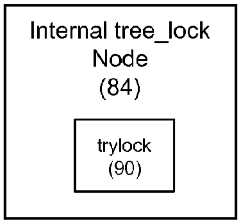

FIG. 15

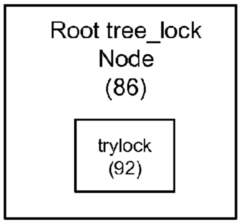

FIG. 16

```
#define MY_BIT 0x1
int myflag;
spinlock_t my_lock;

struct tree_lock __thread *my_tree_leaf;

bool my_check(void *my_data)
{
  int *mdp = my_data;

  return !!(*mdp & MY_BIT);
}

void set_my_bit(void)
{
  if (!tree_try_lock(my_tree_leaf, my_check, &myflag))
    return;
  spin_lock(&my_lock);
  tree_unlock(my_tree_leaf);
  if (myflag & MY_BIT) {
    spin_unlock(&my_lock);
    return;
  }
  myflag |= MY_BIT;
  spin_unlock(&my_lock);
}
```

FIG. 17

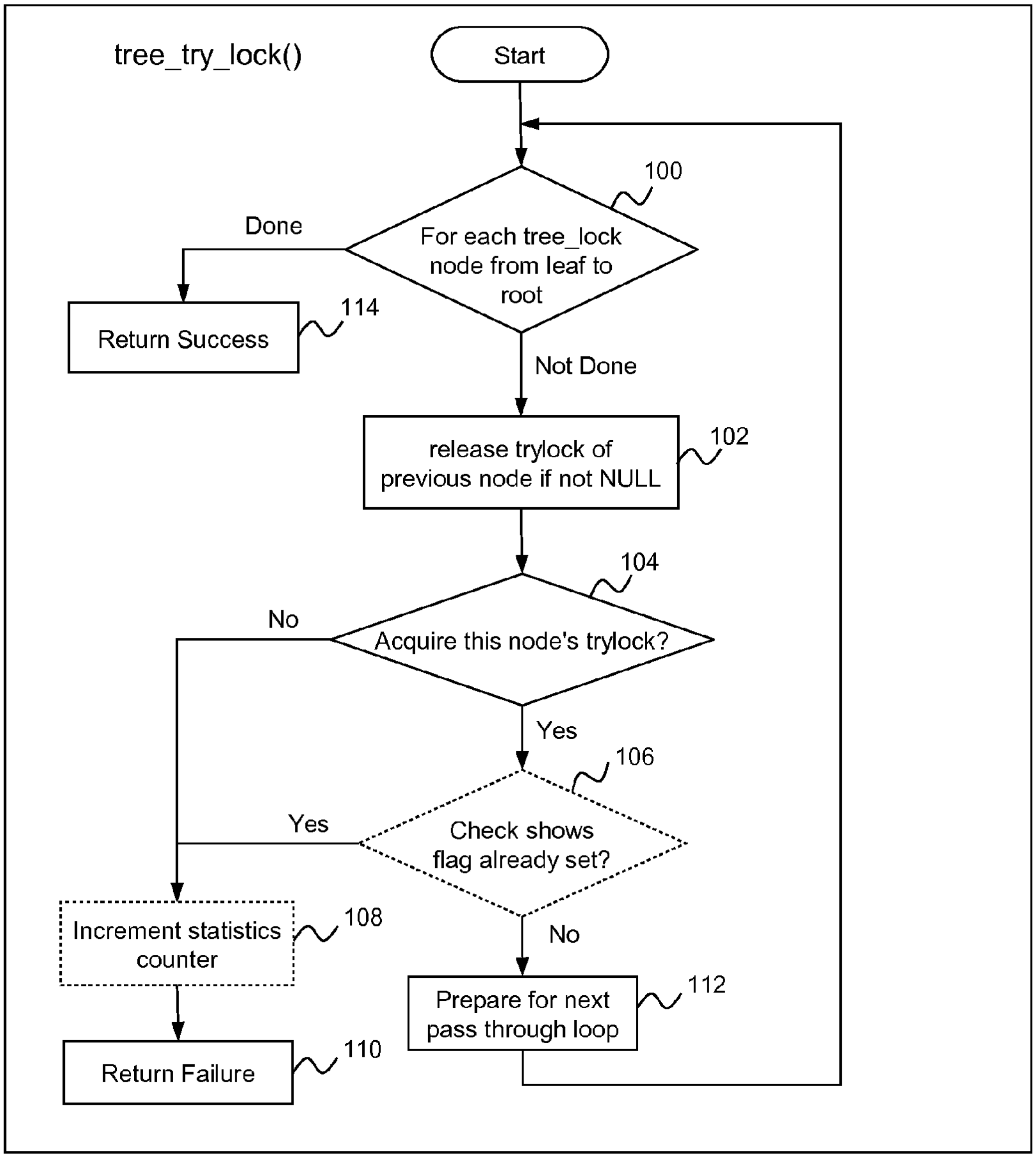
tree_try_lock()
Start
100
For each tree_lock node from leaf to root
Done
Return Success
114
Not Done
release trylock of previous node if not NULL
102
104
No
Acquire this node's trylock?
Yes
106
Yes
Check shows flag already set?
Increment statistics counter
108
No
Prepare for next pass through loop
112
Return Failure
110

FIG. 18

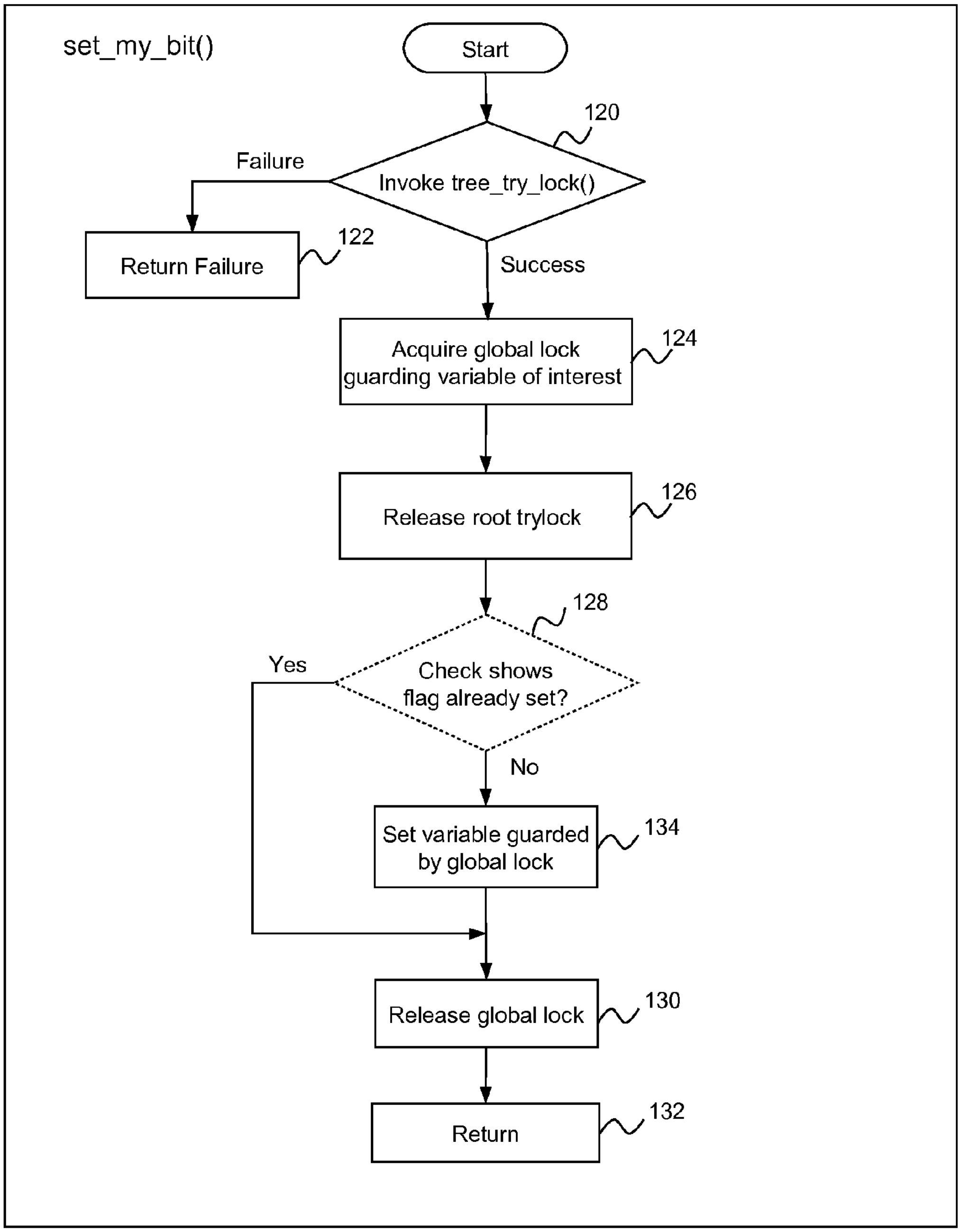
set_my_bit()
Start
120
Invoke tree_try_lock()
Failure
Return Failure
122
Success
Acquire global lock guarding variable of interest
124
Release root trylock
126
128
Check shows flag already set?
Yes
No
Set variable guarded by global lock
134
Release global lock
130
Return
132

FIG. 19

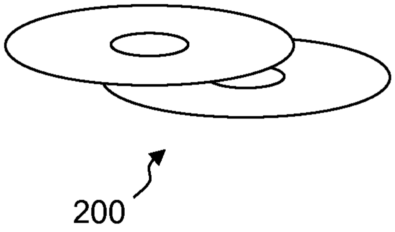

FIG. 20

HIGHLY SCALABLE TREE-BASED TRYLOCK

BACKGROUND

1. Field

The present disclosure relates to computer systems and methods in which data resources are shared among data consumers while preserving data integrity and consistency relative to each consumer. More particularly, the disclosure concerns a hierarchical locking technique that may be implemented as part of a mutual exclusion mechanism known as "read-copy update," or in other computing environments.

2. Description of the Prior Art

By way of background, read-copy update (also known as "RCU") is a mutual exclusion technique that permits shared data to be accessed for reading without the use of locks, writes to shared memory, memory barriers, atomic instructions, or other computationally expensive synchronization mechanisms, while still permitting the data to be updated (modify, delete, insert, etc.) concurrently. The technique is well suited to both uniprocessor and multiprocessor computing environments wherein the number of read operations (readers) accessing a shared data set is large in comparison to the number of update operations (updaters), and wherein the overhead cost of employing other mutual exclusion techniques (such as locks) for each read operation would be high. By way of example, a network routing table that is updated at most once every few minutes but searched many thousands of times per second is a case where read-side lock acquisition would be quite burdensome.

The read-copy update technique implements data updates in two phases. In the first (initial update) phase, the actual data update is carried out in a manner that temporarily preserves two views of the data being updated. One view is the old (pre-update) data state that is maintained for the benefit of read operations that may have been referencing the data concurrently with the update. The other view is the new (post-update) data state that is seen by operations that access the data following the update. In the second (deferred update) phase, the old data state is removed following a "grace period" that is long enough to ensure that the first group of read operations will no longer maintain references to the pre-update data. The second-phase update operation typically comprises freeing a stale data element to reclaim its memory. In certain RCU implementations, the second-phase update operation may comprise something else, such as changing an operational state according to the first-phase update.

FIGS. **1**A-**1**D illustrate the use of read-copy update to modify a data element B in a group of data elements A, B and C. The data elements A, B, and C are arranged in a singly-linked list that is traversed in acyclic fashion, with each element containing a pointer to a next element in the list (or a NULL pointer for the last element) in addition to storing some item of data. A global pointer (not shown) is assumed to point to data element A, the first member of the list. Persons skilled in the art will appreciate that the data elements A, B and C can be implemented using any of a variety of conventional programming constructs, including but not limited to, data structures defined by C-language "struct" variables. Moreover, the list itself is a type of data structure.

It is assumed that the data element list of FIGS. **1**A-**1**D is traversed (without locking) by multiple readers and occasionally updated by updaters that delete, insert or modify data elements in the list. In FIG. **1**A, the data element B is being referenced by a reader **r1**, as shown by the vertical arrow below the data element. In FIG. **1**B, an updater **u1** wishes to update the linked list by modifying data element B. Instead of simply updating this data element without regard to the fact that **r1** is referencing it (which might crash **r1**), **u1** preserves B while generating an updated version thereof (shown in FIG. **1**C as data element B') and inserting it into the linked list. This is done by **u1** acquiring an appropriate lock (to exclude other updaters), allocating new memory for B', copying the contents of B to B', modifying B' as needed, updating the pointer from A to B so that it points to B', and releasing the lock. In current versions of the Linux® kernel, pointer updates performed by updaters can be implemented using the rcu_assign_pointer( ) primitive. As an alternative to locking during the update operation, other techniques such as non-blocking synchronization or a designated update thread could be used to serialize data updates. All subsequent (post update) readers that traverse the linked list, such as the reader **r2**, will see the effect of the update operation by encountering B' as they dereference B's pointer. On the other hand, the old reader **r1** will be unaffected because the original version of B and its pointer to C are retained. Although **r1** will now be reading stale data, there are many cases where this can be tolerated, such as when data elements track the state of components external to the computer system (e.g., network connectivity) and must tolerate old data because of communication delays. In current versions of the Linux® kernel, pointer dereferences performed by readers can be implemented using the rcu_dereference( ) primitive.

At some subsequent time following the update, **r1** will have continued its traversal of the linked list and moved its reference off of B. In addition, there will be a time at which no other reader process is entitled to access B. It is at this point, representing an expiration of the grace period referred to above, that **u1** can free B, as shown in FIG. **1**D.

FIGS. **2**A-**2**C illustrate the use of read-copy update to delete a data element B in a singly-linked list of data elements A, B and C. As shown in FIG. **2**A, a reader **r1** is assumed be currently referencing B and an updater **u1** wishes to delete B. As shown in FIG. **2**B, the updater **u1** updates the pointer from A to B so that A now points to C. In this way, **r1** is not disturbed but a subsequent reader **r2** sees the effect of the deletion. As shown in FIG. **2**C, **r1** will subsequently move its reference off of B, allowing B to be freed following the expiration of a grace period.

In the context of the read-copy update mechanism, a grace period represents the point at which all running tasks (e.g., processes, threads or other work) having access to a data element guarded by read-copy update have passed through a "quiescent state" in which they can no longer maintain references to the data element, assert locks thereon, or make any assumptions about data element state. By convention, for operating system kernel code paths, a context switch, an idle loop, and user mode execution all represent quiescent states for any given CPU running non-preemptible code (as can other operations that will not be listed here). The reason for this is that a non-preemptible kernel will always complete a particular operation (e.g., servicing a system call while running in process context) prior to a context switch.

In FIG. **3**, four tasks 0, 1, 2, and 3 running on four separate CPUs are shown to pass periodically through quiescent states (represented by the double vertical bars). The grace period (shown by the dotted vertical lines) encompasses the time frame in which all four tasks that began before the start of the grace period have passed through one quiescent state. If the four tasks 0, 1, 2, and 3 were reader tasks traversing the linked lists of FIGS. **1**A-**1**D or FIGS. **2**A-**2**C, none of these tasks having reference to the old data element B prior to the grace period could maintain a reference thereto following the grace period. All post grace period searches conducted by these tasks would bypass B by following the updated pointers created by the updater.

Grace periods may be synchronous or asynchronous. According to the synchronous technique, an updater performs the first phase update operation, blocks (waits) until a grace period has completed, and then implements the second phase update operation, such as by removing stale data. According to the asynchronous technique, an updater performs the first phase update operation, specifies the second phase update operation as a callback, then resumes other processing with the knowledge that the callback will eventually be processed at the end of a grace period. Advantageously, callbacks requested by one or more updaters can be batched (e.g., on callback lists) and processed as a group at the end of an asynchronous grace period. This allows asynchronous grace period overhead to be amortized over plural deferred update operations.

More recently, RCU grace period processing has been adapted to account for processor low power states (such as, on Intel® processors, the C1E halt state, or the C2 or deeper halt states). Operating systems can take advantage of low power state capabilities by using mechanisms that withhold regular timer interrupts from processors (in a low power state) unless the processors need to wake up to perform work. The dynamic tick framework (also called "dyntick" or "nohz") in existing versions of the Linux® kernel is one such mechanism. In RCU implementations designed for low power applications in the Linux® kernel, a compiler configuration option called RCU_FAST_NO_HZ is available. This option allows processors to be placed in low power states even if there are pending RCU callbacks, provided none require immediate invocation and the processor is not needed for grace period advancement processing.

One characteristic of the RCU_FAST_NO_HZ option is that quiescent states are periodically forced in order to expedite callback processing so that processors can enter low power states more quickly. Quiescent state forcing is regulated by a global lock that serializes access to the quiescent state forcing mechanism. The global quiescent state forcing lock is acquired only with a trylock primitive called "raw_spin_trylock_irqsave( )," which either immediately acquires the lock or returns failure. As such, the contention on the global quiescent state forcing lock should be zero. Unfortunately, on large systems (thousands of CPUs), enabling RCU_FAST_NO_HZ has historically been susceptible to extreme memory contention due to a high rate of attempts to acquire the global quiescent state forcing lock, resulting in throughput dropping to nearly zero. This high level of memory contention can also result from RCU's implementation of the asynchronous callback processing primitive "call_rcu( )," which can invoke quiescent state forcing when large numbers of RCU callbacks are enqueued on the CPU in question.

Although an immediate solution is to disable RCU_FAST_NO_HZ on large systems, this approach results in sub-optimal energy efficiency. Accordingly, there is a need for a technique for acquiring the global quiescent state forcing lock with reduced memory contention. Other RCU operations, as well as many non-RCU operations, could likewise benefit from a locking technique with reduced lock contention in systems with many processors.

SUMMARY

A method, system and computer program product are provided to implement tree-based trylock operations that reduce contention on a root trylock in a computer system having two or more processors operatively coupled to one or more memory devices. In an example embodiment, a lock hierarchy is provided in which plural trylocks are distributed among nodes of a tree-based node structure having a plurality of leaf nodes, one or more internal nodes, and a root node. The processors are assigned to the leaf nodes in a distributed and balanced manner in order to minimize memory contention on the trylocks. A trylock acquisition operation is implemented on a selected one of the processors for acquiring a root trylock associated with the root node. The trylock acquisition operation attempts to acquire one of the trylocks at each node of the node structure that lies on a traversal path beginning at one of the leaf nodes, passing through one or more of the internal nodes, and ending at the root node. The trylock acquisition operation succeeds if each trylock on the traversal path is acquired, and fails if any trylock on the traversal path cannot be acquired. A trylock housekeeping operation releases all non-root trylocks visited by the trylock acquisition operation, such that if the trylock acquisition operation succeeds, only the root trylock will remain acquired at the end of the operation, and if the trylock acquisition operation fails, none of the trylocks will be remain acquired at the end of the operation.

In an example embodiment, the root trylock guards a guarded operation for which duplicate initiations are redundant, or guards a global lock that in turn guards the guarded operation.

In an example embodiment, the guarded operation comprises read-copy update quiescent state forcing.

In an example embodiment, the trylock acquisition operation further includes checking, at each node on the traversal path, a condition indicating that an operation protected by the root trylock has already been initiated by another one of the processors, and failing the trylock acquisition operation if the condition exists.

In an example embodiment, the trylock housekeeping operation is performed at each of the nodes on the traversal path by releasing a trylock acquired at an immediately preceding node.

In an example embodiment, a global lock acquisition is performed to acquire a global lock after the trylock acquisition operation successfully acquires the root trylock, the root trylock being released if the global lock acquisition is successful.

In an example embodiment, the global lock acquisition operation includes checking a condition indicating that an operation guarded by the global lock has already been initiated by another one of the processors, and failing the global lock acquisition operation if the condition exists.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other features and advantages will be apparent from the following more particular description of example embodiments, as illustrated in the accompanying Drawings, in which:

FIGS. **1**A-**1**D are diagrammatic representations of a linked list of data elements undergoing a data element replacement according to a conventional read-copy update mechanism;

FIGS. **2**A-**2**C are diagrammatic representations of a linked list of data elements undergoing a data element deletion according to a conventional read-copy update mechanism;

FIG. **3** is a flow diagram illustrating a grace period in which four processes pass through a quiescent state;

FIG. **4** is a functional block diagram showing a multiprocessor computing system that may be implemented in accordance with the present disclosure;

FIG. **5** is a functional block diagram showing an RCU subsystem that may be provided in the computer system of FIG. **4**;

FIG. **6** is a functional block diagram showing an example RCU node hierarchy that may be implemented in accordance with the present disclosure;

FIG. **7** is a functional block diagram showing components of a leaf RCU node in the RCU node hierarchy of FIG. **6**;

FIG. **8** is a functional block diagram showing components of an internal RCU node in the RCU node hierarchy of FIG. **6**;

FIG. **9** is a functional block diagram showing components of a root RCU node in the RCU node hierarchy of FIG. **6**;

FIG. **10** is a functional block diagram showing a set of RCU subsystem support functions that be provided by the RCU subsystem of FIG. **5**;

FIG. **11** illustrates example C-language code for an RCU force_quiescent_state( ) function that may be implemented in accordance with the present disclosure;

FIG. **12** illustrates example C-language code for implementing a hierarchy of tree_lock nodes that each contain a trylock, and for implementing a tree_try_lock( ) function, and for implementing a tree_unlock function;

FIG. **13** is a a functional block diagram showing an example implementation of the hierarchy of tree_lock nodes that each contain a trylock, as defined in the example code of FIG. **12**;

FIG. **14** is a functional block diagram showing components of a leaf tree_lock node in the node hierarchy of FIG. **13**;

FIG. **15** is a functional block diagram showing components of an internal tree_lock node in the node hierarchy of FIG. **13**;

FIG. **16** is a functional block diagram showing components of a root tree_lock node in the node hierarchy of FIG. **13**;

FIG. **17** illustrates example C-language code for using the tree_try_lock( ) and tree_unlock( ) functions of FIG. **12**;

FIG. **18** is a flow diagram showing example operations of the tree_try_lock( ) function of FIG. **12**;

FIG. **19** is a flow diagram showing example operations of the code shown tree_try_lock( ) function use code shown in FIG. **17**; and

FIG. **20** is a diagrammatic illustration showing example computer-readable non-transitory data storage media that may be used to provide a computer program product in accordance with the present disclosure.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

Introduction

The present disclosure provides a hierarchy of conditional trylocks, with a trylock at each node of the hierarchy, including a root trylock at the root node of the hierarchy that guards an operation for which duplicate initiations are redundant, or which indirectly guards the operation by guarding a global lock that directly guards the operation. One example of such an operation is quiescent state forcing, as described in the Background section above. In order to reduce contention on the root trylock, each CPU (or thread) is assigned to one of the leaf nodes and conditionally acquires a trylock at each level of the hierarchy in an at-most once manner, beginning at its assigned leaf node and moving upwardly through the hierarchy in leaf-to-root fashion.

To conditionally acquire a given trylock, a CPU/thread asserts the trylock and immediately checks the result. If the acquisition fails, the overall acquisition fails. Otherwise, if the acquisition succeeds, the CPU/thread moves up to the next level of the hierarchy and repeats. Regardless whether the root trylock acquisition effort succeeds or fails at some point along the node traversal path, all non-root trylocks must be released. Releasing these lower level trylocks may be efficiently handled by the CPU/thread at each node as it moves upwardly through the lock hierarchy. In particular, after (or before) the CPU/thread attempts to acquire a trylock at a given level of the hierarchy, it may release the prior trylock acquired in the immediately preceding level. Other trylock release methods may also be used.

If the CPU/thread acquires the trylock at the root of the hierarchy, it has acquired the root trylock. Additionally, a global lock that protects a particular operation may be provided as a separate lock that is acquired by the CPU/thread after it acquires the root trylock. In the example embodiment in which the operation in question is RCU quiescent state forcing, such an additional global lock is used because it already exists in RCU implementations for the Linux® kernel. The purpose of the global lock is to synchronize setting of a flag and a wakeup to the quiescent state forcing operation protected by the lock. In this embodiment, additional efficiency may be obtained by checking the flag at each level of the hierarchy. If the flag is already set, then a quiescent state forcing operation has already been requested and there is no need to push further up the hierarchy. Other embodiments may likewise use this technique, checking the state of a flag (or other condition indicator) as the lock hierarchy is traversed in order to avoid wasted effort.

EXAMPLE EMBODIMENTS

Turning now to the figures, wherein like reference numerals represent like elements in all of the several views, FIG. **4** illustrates an example multiprocessor computer system in which the grace period processing technique described herein may be implemented. In FIG. **4**, a computer system **2** includes multiple processors $\mathbf{4}_1$, $\mathbf{4}_2$ . . . $\mathbf{4}_n$, a system bus **6**, and a program memory **8**. There are also cache memories $\mathbf{10}_1$, $\mathbf{10}_2$ . . . $\mathbf{10}_n$ and cache controllers $\mathbf{12}_1$, $\mathbf{12}_2$ . . . $\mathbf{12}_n$ respectively associated with the processors $\mathbf{4}_1$, $\mathbf{4}_2$ . . . $\mathbf{4}_n$. A conventional memory controller **14** is again associated with the memory **8**. As shown, the memory controller **14** may reside separately from processors $\mathbf{4}_2$ . . . $\mathbf{4}_n$ (e.g., as part of a chipset).

The computer system **2** may represent any of several different types of computing apparatus. Such computing apparatus may include, but are not limited to, general purpose computers, special purpose computers, portable computing devices, communication and/or media player devices, set-top devices, embedded systems, and other types of information handling machines. The term "processor" as used with reference to the processors $\mathbf{4}_1$, $\mathbf{4}_2$ . . . $\mathbf{4}_n$ encompasses any program execution unit capable of executing program instructions, including but not limited to a packaged integrated circuit device (such as a microprocessor), a processing core within a packaged integrated circuit device (such as a microprocessor core), or a hardware thread comprising one or more functional units within a processing core (such as an SMT thread). Each such execution unit may be referred to as a CPU (central processing unit). The processors $\mathbf{4}_1$, $\mathbf{4}_2$ . . . $\mathbf{4}_n$ may be situated within a single computing device or node (e.g., as part of a single-node SMP system) or they may be distributed over plural nodes (e.g., as part of a NUMA system, a cluster, or a cloud). The memory **8** may comprise any type of tangible storage medium capable of storing data in computer readable form for use in program execution, including but not limited to, any of various types of random access memory (RAM), various flavors of programmable read-only memory (PROM) (such as flash memory), and other types of primary storage (i.e., program memory). The cache memories **10**$_1$, **10**$_2$ . . . **10**$_n$ may be implemented in several levels (e.g., as level 1, level 2 and level 3 caches) and the cache controllers **12**$_1$, **12**$_2$ . . . **12**$_n$ may collectively represent the cache controller logic that supports each cache level. As illustrated, the memory controller **14** may reside separately from processors **4**$_1$, **4**$_2$ . . . **4**$_n$, for example, as part of a discrete chipset. Alternatively, the memory controller **14** could be provided by plural memory controller instances that are respectively integrated with the processors **4**$_1$, **4**$_2$ . . . **4**$_n$.

Each CPU embodied by a given processor **4** is operable to execute program instruction logic under the control of a software program stored in the memory **8** (or elsewhere). As part of this program execution logic, update operations (updaters) **18** may execute within a process, thread, or other execution context (hereinafter "task") on any of the processors **4**. Each updater **18** runs periodically to perform updates on a set of shared data **16** that may be stored in the shared memory **8** (or elsewhere). In FIG. **4**, reference numerals **18**$_1$, **18**$_2$ . . . **18**$_n$ illustrate individual data updaters that respectively execute on the several processors **4**$_1$, **4**$_2$ . . . **4**$_n$. As described in the "Background" section above, the updates performed by an RCU updater can include modifying elements of a linked list, inserting new elements into the list, deleting elements from the list, and other types of operations. To facilitate such updates, the processors **4** may be programmed from instructions stored in the memory **8** (or elsewhere) to implement a read-copy update (RCU) subsystem **20** as part of their processor functions. In FIG. **4**, reference numbers **20**$_1$, **20**$_2$ . . . **20**$_n$ represent individual RCU instances that may periodically execute on the several processors **4**$_1$, **4**$_2$ . . . **4**$_n$. Any given processor **4** may also execute a read operation (reader) **21**. Each reader **21** runs from program instructions stored in the memory **8** (or elsewhere) in order to periodically perform read operations on the set of shared data **16** stored in the shared memory **8** (or elsewhere). In FIG. **4**, reference numerals **21**$_1$, **21**$_2$ . . . **21**$_n$ illustrate individual reader instances that may respectively execute on the several processors **4**$_1$, **4**$_2$ . . . **4**$_n$. Such read operations will typically be performed far more often than updates, this being one of the premises underlying the use of read-copy update. Moreover, it is possible for several of the readers **21** to maintain simultaneous references to one of the shared data elements **16** while an updater **18** updates the same data element.

During operation of the computer system **2**, an updater **18** will occasionally perform an update to one of the shared data elements **16**. In accordance the philosophy of RCU, a first-phase update may be performed in a manner that temporarily preserves a pre-update view of the shared data element for the benefit of readers **21** that may be concurrently referencing the shared data element during the update operation. Following the first-phase update, the updater **18** may register a callback with the RCU subsystem **20** for the deferred destruction of the pre-update view following a grace period (second-phase update). As described in the "Background" section above, this is known as asynchronous grace period processing. Alternatively, the updater **18** may request a synchronous expedited grace period.

The grace period processing performed by the RCU subsystem **20** entails starting new grace periods and detecting the end of old grace periods so that the RCU subsystem **20** knows when it is safe to free stale data (or take other actions). Grace period processing may further entail the management of callback lists that accumulate callbacks until they are ripe for batch processing at the end of a given grace period.

Turning now to FIG. **5**, example components of the RCU subsystem **20** are shown. Among these components is a set of RCU subsystem data structures **30** that includes an RCU state structure **32** for tracking per-processor quiescent states. For purposes of the present embodiment, it may be assumed that the RCU subsystem **20** is configured as a hierarchical RCU implementation, as is conventionally provided in large multiprocessor computer systems running the Linux® kernel. In that case, the RCU subsystem data structures **30** will further include a tree **34** of RCU nodes embedded as a linear array within the RCU state structure **32**. FIG. **6** illustrates an example three-level RCU node tree that includes six bottom-level leaf RCU nodes **36**, three intermediate level internal RCU nodes **38**, a top level root RCU node **40**.

In addition to the embedded RCU node tree **34**, the RCU state structure **32** includes a quiescent state indicator **42** for indicating when all of the processors **4** have passed through a quiescent state and a grace period may be ended. The RCU state structure **32** also includes a quiescent state force flag **44** to indicate that a quiescent state forcing operation has been requested by one of the processors **4**.

One of the purposes of the RCU node tree **34** is to reduce contention for the quiescent state indicator **42**, which could be problematic if the indicator was protected by a single global lock. See P. McKenney, *Hierarchical RCU*, <lwn.net/Articles/305782>, Nov. 4, 2008. Instead of all the processors **4** using a global lock to access the quiescent state indicator **42**, subsets of the processors are assigned to individual leaf RCU nodes **36**. Similarly, subsets of the leaf RCU nodes **36** are assigned to individual internal RCU nodes **38**. The internal RCU nodes **38** are likewise assigned to the root RCU node **40**. As shown in FIG. **7**, each leaf RCU node **36** maintains an array **36**A of quiescent state bits, with each bit corresponding to one of the leaf node's assigned processors. By way of example, FIG. **7** shows four quiescent state bits associated with four of the processors **4**. A bit array lock **36**B serializes access to the quiescent state bit array **36**A. Similarly, each internal RCU node **38** maintains an array **38**A of quiescent state bits, with each bit corresponding to one of the internal node's assigned RCU leaf nodes **36**. A bit array lock **38**B serializes access to the quiescent state bit array **38**A. The root RCU node **40** maintains an array **40**A of quiescent state bits to which the internal RCU nodes **38** are respectively assigned. A bit array lock **40**B serializes access to the quiescent state bit array **40**A.

When a processor **4** passes through a quiescent state, it asserts the RCU node lock **36**B in its assigned leaf RCU node **36**, and sets its assigned quiescent state bit in the bit array **36**A. To propagate the quiescent state information upwardly through the RCU node tree **34**, the last processor **4** to set its bit in a leaf RCU node **36** acquires the RCU node lock **38**B in the internal RCU node **38** to which the leaf node is assigned, and sets the internal node's quiescent state bit in the bit array **38**A. In similar fashion, the last processor **4** to set a bit in an internal RCU node **38** acquires the RCU node lock **40**B in the root RCU node **40**, and sets the root node's quiescent state bit in the bit array **40**A. Finally, the last processor **4** to set a bit in the root node bit array **40**A accesses and sets the quiescent state indicator **42**, thereby signaling that the current RCU grace period may end.

It should be noted that a production read-copy update implementation will typically include many additional data structures that are not shown in FIG. **5**. A discussion of such data structures is omitted for ease of description and in order to focus attention on the tree-based trylock technique disclosed herein. As will be described in more detail below, the RCU node tree **34** may be conveniently used to provide a hierarchical tree structure for the new trylock technique. Other hierarchical trees may be used in other implementations.

Returning now to FIG. **5**, the components of the RCU subsystem **20** also include several RCU subsystem support functions **50**, namely, an RCU reader API (Application Programming Interface) **52**, an RCU updater API **54**, and a set of grace period detection and callback functions **56**.

As shown in FIG. **10**, the RCU reader API **52** comprises a reader registration component **52**A and a reader unregistration component **52**B. These components are respectively invoked by readers **21** as they enter and leave their RCU read-side critical sections. This allows the RCU subsystem **20** to track reader operations and determine when readers are engaged in RCU-protected read-side critical section processing. In an example embodiment, the reader registration component **52**A and the reader unregistration component **52**B may be respectively implemented using the rcu_read_lock( ) and rcu_read_unlock( ) primitives found in existing read-copy update implementations.

As also shown in FIG. **10**, the RCU updater API **54** comprises a register callback component **54**A. The register callback component **54**A is used by updaters **18** to register a callback following a first-phase update to a shared data element **16**. An invocation of the register callback component **54**A initiates processing that places the callback on one of the RCU callback lists **34** associated with the processor **4** that runs the updater **18**. This may start an asynchronous grace period (if one is not already underway) so that the callback can be processed after the grace period has ended as part of second-phase update processing to remove stale data (or perform other actions). In an example embodiment, the register callback component **54**A may be implemented using the existing call_rcu( ) primitive found in conventional read-copy update implementations.

With continuing reference to FIG. **10**, the grace period detection and callback processing component **56** of the RCU subsystem **20** include a force quiescent state component **58** that implements the tree-based trylock technique disclosed herein. The grace period detection and callback processing component **56** also includes a number of other conventional RCU components **64** that are responsible for various operations, such as starting new grace periods, detecting the end of old grace periods, and processing callbacks as grace periods end. A discussion of such components is omitted for ease of description and in order to focus attention on the tree-based trylock technique disclosed herein.

As described in the Introduction section above, the tree-based trylock technique disclosed herein contemplates a hierarchical tree of nodes, with a trylock at each node, and including a root trylock at the root node of the hierarchy. As is known in the art, a trylock is a lock having at-most-once semantics, such that lock acquisition is tried only once and either succeeds or fails. The processors **4** are assigned to different leaf nodes in a distributed and balanced manner in order to minimize memory contention. A CPU or a thread running within a CPU that desires to acquire the root trylock begins at one of the leaf nodes of the lock hierarchy, and works its way to the root trylock node following a traversal path, conditionally acquiring trylocks at lower level nodes as it does so, and releasing all trylocks and abandoning the acquisition effort if it fails to acquire a trylock at any given level. As stated above, in a hierarchical RCU implementation as described above in connection FIGS. **5-9**, the RCU nodes **36**, **38** and **40** of the RCU node hierarchy **34** provide convenient data structures for holding the tree-based trylocks contemplated by the present disclosure. Such tree-based trylocks are shown in the RCU node diagrams of FIGS. **7**, **8** and **9**, and are identified as force quiescent state (FQS) locks insofar as the present embodiment uses the trylocks to serialize access to the quiescent state force flag **44** shown in FIG. **5**. In FIG. **7**, the leaf RCU node **36** is shown as having a force quiescent state trylock **66**. In FIG. **8**, the internal RCU node **38** is shown as having a force quiescent state trylock **68**. In FIG. **9**, the root RCU node **40** is shown as having a root force quiescent state trylock **70**. In addition, the root RCU node **40** includes a global force quiescent state lock **72** (which may or may not be a trylock), that protects access to the quiescent state force indicator **44**.

With reference now to FIG. **11**, example C-language pseudocode that may be used to implement the force quiescent state component **58** is shown. The function name given to the quiescent state component **58** is “force_quiescent_state( ).” The argument to this function is a pointer “*rsp” to the RCU state structure **32** shown in FIG. **5**. The purpose of the function is to set the quiescent state force flag **44**, which is given the name “GP_FLAGS_FQS” in the code, and is implemented as a bit in flags field of the RCU state structure **32** called “rsp→gp_flags.” Line **8** of the code disables interrupts in order to pin the current task onto a particular CPU, allowing line **9** to obtain a stable reference to this CPU’s leaf RCU node **36** (named “rnp”). As an alternative, it is possible to take a snapshot of the CPU number without disabling interrupts. This alternative approach risks additional cache misses, but provides better scheduling latency. Moreover, a user-level implementation of the disclosed tree-based trylock technique would normally be incapable of disabling interrupts.

The loop spanning lines **10-21** traverses the RCU node tree **34** (see FIG. **6**) from leaf to root. Line **11** checks the quiescent state flag **44** to see if another task already performed the required work, and if not, line **12** attempts to acquire the current RCU node’s force quiescent state trylock (see elements **66**, **68** and **70** of FIGS. **7**, **8** and **9**, respectively), referred to in the code as “fqslock.” To expedite the memory access, each force quiescent state trylock **66**, **68** or **70** may be aligned to its own cache line. The Boolean result of lines **11** and **12** is stored in the “ret” variable. If line **13** determines that a trylock acquired during the previous pass through the loop is still being held, line **14** releases it using the tree unlock component **62** of FIG. **10**. Line **15** tests the “ret” variable. If the line **11** determined that the quiescent state force flag **44** is already set, or if the attempt on line **12** to acquire the force quiescent state trylock **66**, **68** or **70** failed, line **16** increments a statistical counter (which can lose counts), line **17** re-enables interrupts, and line **18** returns to the caller. Otherwise, line **20** prepares for the next pass through the loop.

Upon exit from the loop, the root RCU node **40** will have been reached and the root force quiescent state trylock **70** will have been acquired. Line **22** unconditionally acquires the RCU node’s global force quiescent state lock **72**, whose name in the code is simply “lock.” Line **23** releases the root force quiescent state lock **70** using the tree unlock component **62** of FIG. **10**. Line **24** optionally makes one final check of the quiescent state force flag **44** to see if it is already set by another task, and if so, lines **25-27** increment the statistical counter, release the root RCU node’s global force quiescent state lock **72**, and return to the caller. Otherwise, line **29** sets the quiescent state force flag **44**, line **30** releases the root RCU node’s global force quiescent state lock **72**, and line **31** wakes up a thread that attempts to force quiescent states in order to end the current grace period.

It is possible to abstract the forgoing tree-based trylock operations for use in other environments, it being understood that the RCU force quiescent state scenario described above is merely on example embodiment of the disclosed subject matter. More generally, any case where a large number of CPUs might need to awaken or otherwise signal a specific CPU/thread to perform an operation with at-most-once semantics can use the disclosed mechanism. This sort of arrangement offers cache-locality advantages (and also a reduction in synchronization overhead) in cases where a specific type of processing can be guaranteed to never consume more than one CPU's worth of processing.

FIGS. **12-16** illustrate one example abstraction of the tree-based trylock operations performed by the force_quiescent_state( ) function of FIG. **11** (which in turn is an example implementation of the force quiescent state component **58** of FIG. **10**).

The first few lines of FIG. **12** illustrates an abstract "tree_lock" node that is analogous to the RCU nodes **36**, **38** and **40** of the RCU node tree **34** of FIG. **6**. FIG. **12** also illustrates an abstract "tree_try_lock( )" function that is analogous to the loop spanning lines **9-21** of the force_quiescent_state( ) function in FIG. **11**. As previously described, this loop attempts to acquire the root RCU node's force quiescent state trylock **70** shown in FIG. **9**. FIG. **12** likewise illustrates an abstract "tree_unlock( )" function that is analogous to the "raw_spin_unlock( )" function on line **23** in FIG. **11** that unlocks the root RCU node's force quiescent state trylock **70**.

Lines **1-6** of FIG. **12** show the structure of the aforementioned "tree_lock" node. A set of tree_lock nodes is arranged hierarchically in a tree of such nodes (a "tree_lock tree"), one example of which is shown by reference number **80** in FIG. **13**. The tree_lock tree **80** includes a set of leaf tree_lock nodes **82**, a set of internal tree_lock nodes **84** and a top level root tree_lock node **86**. As shown in line **2** of FIG. **12**, each of the tree_lock nodes **82**, **84** and **86** contains a trylock that is named "try_lock." As shown in FIG. **14**, the trylock in the leaf tree_lock nodes **82** is identified by reference number **88**, the trylock in the internal tree_lock nodes **84** is identified by reference number **90**, and the trylock in the root tree_lock node **82** is identified by reference number **92** (the root trylock). As shown in line **3**, each of the tree_lock nodes **82**, **84** and **86** also contains a reference to the node's immediate parent, with the root node's→parent field being NULL. As shown in line **4**, each of the lower level tree_lock nodes **82** and **84** also contains a reference to the root tree_lock node **86**, as does the root tree_lock node itself. As shown in line **5**, each of the tree_lock nodes **82**, **84** and **86**, may optionally contain a "failcount" field. This field is used as a failure counter that is analogous to the statistics counter used in lines **16** and **25** of FIG. **11**, except that it is maintained on a per-node basis rather than globally as in FIG. **11**. The procedures to initialize the full tree_lock tree **80** and to point threads at their respective leaf nodes are straightforward tasks that will not be belabored here.

The tree_try_lock( ) function shown on lines **8-26** of FIG. **12** traverses the tree_lock tree **80** in an effort to acquire the root trylock **92**. The "*check( )" function pointer passed as an argument in line **9** is analogous to the check in line **11** of the force_quiescent_state( ) function of FIG. **11** to determine if a flag or other variable guarded by the root lock being acquired is already set. The check( ) function takes *arg as its sole parameter. The loop spanning lines **15-24** traverses the tree_lock tree **80** from leaf to root, starting with a specified leaf tree_lock node **82** passed as an argument to the tree_try_lock( ) function. Line **16** sets local variable "ret" to true if either the check( ) function determines that the required work is already done or the "spin_trylock( )" function fails to acquire the current tree_lock node's trylock (**88**, **90** or **92**), either of which will terminate the traversal up the tree_lock tree **80**. Lines **17** and **18** release the trylock acquired (if any) during the previous pass through the loop. Line **20** increments this node's failure counter and line **21** returns to the caller to indicate failure. Otherwise, line **23** prepares for the next pass through the loop. If these operations succeed in locking the root trylock **92**, line **25** reports success to the caller. Lines **28-33** show the tree_unlock( ) function, which must be called after the tree_try_lock( ) function reports success. This function simply releases the root trylock **92**.

An example usage of the tree-based try lock technique of FIGS. **12-16** is shown in FIG. **17**. Line **2** of FIG. **17** declares the variable protected by the root trylock **92** (a flag variable called "myflag" that is analogous to the gp_flags variable checked in lines **11**, **24** and **29** of FIG. **11**). Line **1** defines the value to which myflag is be set in order to initiate some operation for which duplicate initiations are redundant. This value is defined as a flag called "MY_BIT" that has magnitude of 0x1. The MY_BIT value is analogous to the RCU_GP_FLAG_FQS value checked in lines **11**, **24** and **29** of FIG. **11**. Line **3** of FIG. **17** declares a global lock called "my_lock" that protects the myflag variable. This global lock could be located anywhere in memory, including in the root tree_lock node **86** if desired. Optionally, the global lock could be eliminated and the root trylock **92** could be used exclusively to guard the myflag variable.

FIG. **17** also illustrates an abstract "my_check( )" function and a "set_my_bit( )" function. The my_check( ) function is defined in lines **7-12**. This is the check( ) function that is passed as an argument to tree_try_lock( ) function, as discussed above in connection with FIG. **12**. Its purpose is to check if the variable protected by the global mylock (in this case the myflag variable) has already been set to the desired value (in this case the MY_BIT flag). The set_my_bit( ) function is defined in lines **14-26**. This function uses the tree_try_lock( ) and tree_unlock( ) functions of FIG. **12** to set the MY_BIT flag in the myflag variable. Line **16** invokes tree_try_lock( ) and line **17** returns if it fails (indicating that the root trylock **92** could not be acquired, or that the required work was already done by another task). Line **18** acquires the global mylock that protects the myflag variable, and line **19** invokes tree_unlock( ) to release the root trylock **92**. Note that the call to tree_unlock( ) may be deferred to follow line **25** if reducing memory contention on the global mylock is more important than acquisition latency on this lock. In fact, the call to tree_unlock( ) could be placed anywhere between its current position and line **26**. Lines **20-23** do one last check to see if the MY_BIT flag has already been set in the myflag variable. Note that these lines may be omitted if memory contention on the myflag variable is not a concern. Line **24** sets MY_BIT, and could be optionally followed by code that awakens some other thread or process to perform a desired operation. Finally, line **25** releases the global mylock.

The code of FIGS. **12-17** shows how the disclosed tree-based trylock technique may be used to efficiently and scalably provide the "do-at-most-once" semantics that are required for posting new work to a thread that implements an operation for which duplicate initiations are redundant.

Turning now to FIGS. **18** and **19**, flow diagrams are shown to further elucidate operations of the tree_try_lock( ) function and the set_my_bit function( ). Operations that are considered optional, such as the check( ) function and statistics logging, are shown in dashed-line representation. It is assumed that a tree_lock tree, such as that shown in FIG. **13**, has been established and initialized. Block **100** of FIG. **18** (illustrating operations of the tree_try_lock( ) function) starts the loop of lines **15-26** in FIG. **12**. So long as the root tree_lock node **86** has not been processed, processing proceeds to block **102**, which releases the trylock of the previous tree_lock node so long as the current node is not the initial leaf tree_lock node **82** (see line **18** of FIG. **12**). Preferably, the lower level trylock is not released until after the next block **104** is implemented. However, the lower level trylock release can be performed beforehand. Blocks **104** and **106** implement line **16** of FIG. **12**. Block **104** attempts to acquire the trylock belonging to the current tree_lock node. Optional block **106** checks to see if the MY_BIT flag has already been set. If the trylock acquisition is unsuccessful or if the MY_BIT flag is set, optional block **108** increments the current tree_lock node's failcount counter (see line **20** of FIG. **12**) and block **110** returns failure (see line **21** of FIG. **12**). If the trylock acquisition in block **104** is successful, and if the MY_BIT flag is not already set, block **112** prepares for the next pass through the loop (see line **23** of FIG. **12**). Assuming the loop successfully processes the root tree_lock node **86** in the foregoing manner, block **114** returns success to the caller (see line **25** in FIG. **12**).

Turning now to FIG. **19**, which illustrates the set_my_bit( ) function of FIG. **17**, block **120** attempts to invoke the tree_try_lock( ) function, and returns failure in block **122** if unsuccessful (see lines **16-17** of FIG. **17**). If the root trylock **92** is acquired, block **124** acquires the global mylock guarding the variable of interest, namely, the myflag variable (see line **18** of FIG. **17**). Note that as an alternative to using the global mylock, the root trylock **92** could serve as the global lock that protest the myflag variable. Block **126** releases the root trylock **92** (see line **19** of FIG. **17**). Optional block **128** checks to see if the MY_BIT flag is already set, and if it is, block **130** releases the global mylock and block **132** returns to the caller (see lines **20-22** in FIG. **17**). Assuming the MY_BIT flag is not set, block **134** sets the MY_BIT flag in the myflag variable (see line **24** of FIG. **17**), block **130** releases the global mylock, and block **132** returns to the caller (see line **25** of FIG. **17**).

Accordingly, a highly scalable tree-based trylock technique has been disclosed. It will be appreciated that the foregoing concepts may be variously embodied in any of a data processing system, a machine implemented method, and a computer program product in which programming logic is provided by one or more machine-readable non-transitory data storage media for use in controlling a data processing system to perform the required functions. Example embodiments of a data processing system and machine implemented method were previously described in connection with FIG. **4-19**. With respect to a computer program product, digitally encoded program instructions may be stored on one or more computer-readable non-transitory data storage media for use in controlling a computer or other digital machine or device to perform the required functions. The program instructions may be embodied as machine language code that is ready for loading and execution by the machine apparatus, or the program instructions may comprise a higher level language that can be assembled, compiled or interpreted into machine language. Example languages include, but are not limited to C, C++, assembly, to name but a few. When implemented on a machine comprising a processor, the program instructions combine with the processor to provide a particular machine that operates analogously to specific logic circuits, which themselves could be used to implement the disclosed subject matter.

Example computer-readable non-transitory data storage media for storing such program instructions are shown by reference numerals **8** (memory) and **10** (cache) of the computer system **2** of FIG. **4**. The system **2** may further include one or more secondary (or tertiary) storage devices (not shown) that could store the program instructions between system reboots. A further example of computer-readable non-transitory data storage media that may be used to store the program instructions is shown by reference numeral **200** in FIG. **20**. The data storage media **200** are illustrated as being portable optical storage disks of the type that are conventionally used for commercial software sales, such as compact disk-read only memory (CD-ROM) disks, compact disk-read/write (CD-R/W) disks, and digital versatile disks (DVDs). Such data storage media can store the program instructions either alone or in conjunction with an operating system or other software product that incorporates the required functionality. The computer-readable non-transitory data storage media could also be provided by other portable data storage media (such as floppy disks, flash memory sticks, etc.), or data storage media combined with drive systems (e.g. disk drives). As is the case with the memory **8** and the cache **10** of FIG. **4**, the computer-readable non-transitory data storage media may be incorporated in data processing platforms that have integrated random access memory (RAM), read-only memory (ROM) or other semiconductor or solid state memory, all of which represent further examples of computer-readable non-transitory data storage media. More broadly, the computer-readable non-transitory data storage media could comprise any electronic, magnetic, optical, infrared, semiconductor system or apparatus or device, or any other tangible entity representing a machine, manufacture or composition of matter that can contain, store, communicate, or transport the program instructions for use by or in connection with an instruction execution system, apparatus or device, such as a computer. For all of the above forms of computer-readable non-transitory data storage media, when the program instructions are loaded into and executed by an instruction execution system, apparatus or device, the resultant programmed system, apparatus or device becomes a particular machine for practicing embodiments of the method(s) and system(s) described herein.

Although various example embodiments have been shown and described, it should be apparent that many variations and alternative embodiments could be implemented in accordance with the disclosure. It is understood, therefore, that the invention is not to be in any way limited except in accordance with the spirit of the appended claims and their equivalents.

What is claimed is:

1. A multiprocessor system, comprising:

two or more processors;

a memory coupled to said processors, said memory including a computer useable medium tangibly embodying at least one program of instructions executable by said processors to perform tree-based trylock operations that reduce contention on a root trylock, said operations comprising:

providing a lock hierarchy which plural trylocks are distributed among nodes of a tree-based node structure having a plurality of leaf nodes, one or more internal nodes, and a root node;

assigning said processors to said leaf nodes in a distributed and balanced manner in order to minimize memory contention on said trylocks;

implementing a trylock acquisition operation on a selected one of said processors for acquiring a root trylock associated with said root node;

said trylock acquisition operation including attempting to acquire one of said trylocks at each node of said node structure that lies on a traversal path beginning at one of said leaf nodes, passing through one or more of said internal nodes, and ending at said root node;

said trylock acquisition operation succeeding if each trylock on said traversal path is acquired, and failing if any trylock on said traversal path cannot be acquired; and

performing a trylock housekeeping operation that releases all non-root trylocks visited by said trylock acquisition operation, such that if said trylock acquisition operation succeeds, only said root trylock will be remain acquired at the end of said operation, and if said trylock acquisition operation fails, none of said trylocks will be remain acquired at the end of said operation.

2. The system of claim **1**, wherein said root trylock guards a guarded operation for which duplicate initiations are redundant, or guards a global lock that in turn guards said guarded operation.

3. The system of claim **2**, wherein said guarded operation comprises read-copy update quiescent state forcing.

4. The system of claim **1**, wherein said trylock acquisition operation further includes checking, at each node on said traversal path, a condition indicating that an operation protected by said root trylock has already been initiated by another one of said processors, and failing said trylock acquisition operation if said condition exists.

5. The system of claim **1**, wherein said trylock housekeeping operation is performed at each of said nodes on said traversal path by releasing a trylock acquired at an immediately preceding node.

6. The system of claim **1**, wherein said operations further include performing a global lock acquisition to acquire a global lock after said trylock acquisition operation successfully acquires said root trylock, said root trylock being released if said global lock acquisition is successful.

7. The system of claim **1**, wherein said global lock acquisition operation includes checking a condition indicating that an operation guarded by said global lock has already been initiated by another one of said processors, and failing said global lock acquisition operation if said condition exists.

8. A computer program product, comprising:

one or more machine-readable non-transitory data storage media;

program instructions provided by said one or more data storage media for programming a multiprocessor data processing platform to perform tree-based trylock operations that reduce contention on a root trylock, said operations comprising:

providing a lock hierarchy which plural trylocks are distributed among nodes of a tree-based node structure having a plurality of leaf nodes, one or more internal nodes, and a root node;

assigning said processors to said leaf nodes in a distributed and balanced manner in order to minimize memory contention on said trylocks;

implementing a trylock acquisition operation on a selected one of said processors for acquiring a root trylock associated with said root node;

said trylock acquisition operation including attempting to acquire one of said trylocks at each node of said node structure that lies on a traversal path beginning at one of said leaf nodes, passing through one or more of said internal nodes, and ending at said root node;

said trylock acquisition operation succeeding if each trylock on said traversal path is acquired, and failing if any trylock on said traversal path cannot be acquired; and

performing a trylock housekeeping operation that releases all non-root trylocks visited by said trylock acquisition operation, such that if said trylock acquisition operation succeeds, only said root trylock will be remain acquired at the end of said operation, and if said trylock acquisition operation fails, none of said trylocks will be remain acquired at the end of said operation.

9. The computer program product of claim **8**, wherein said root trylock guards a guarded operation for which duplicate initiations are redundant, or guards a global lock that in turn guards said guarded operation.

10. The computer program product of claim **9**, wherein said guarded operation comprises read-copy update quiescent state forcing.

11. The computer program product of claim **8**, wherein said trylock acquisition operation further includes checking, at each node on said traversal path, a condition indicating that an operation protected by said root trylock has already been initiated by another one of said processors, and failing said trylock acquisition operation if said condition exists.

12. The computer program product of claim **8**, wherein said trylock housekeeping operation is performed at each of said nodes on said traversal path by releasing a trylock acquired at an immediately preceding node.

13. The computer program product of claim **8**, wherein said operations further include performing a global lock acquisition to acquire a global lock after said trylock acquisition operation successfully acquires said root trylock, said root trylock being released if said global lock acquisition is successful.

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